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Nuclear Shadowing in the Structure Function $\mathbf{F_3(x)}$

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ABSTRACT

Nuclear modification of the structure function F_3 is investigated. Although it could be estimated in the medium and large x regions from the nuclear structure function F_2^A, it is essentially unknown at small x. The nuclear structure function F_3^A at small x is investigated in two different theoretical models: a parton-recombination model with Q^2 rescaling and an aligned-jet model. We find that these models predict completely different behavior at small x: *antishadowing* in the first parton model and *shadowing* in the aligned-jet model. Therefore, studies of the ratio F_3^A/F_3^D at small x could be useful in discriminating among different models, which produce similar shadowing behavior in the structure function F_2. We also estimate currently acceptable nuclear modification of F_3 at small x by using F_2^A/F_2^D experimental data and baryon-number conservation.

* Email: kobar, kumanos, or 94sm10@cc.saga-u.ac.jp. Information on our research is available at http://www.cc.saga-u.ac.jp/saga-u/riko/physics/quantum1/structure.html or at ftp://ftp.cc.saga-u.ac.jp/pub/paper/riko/quantum1.

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1. Introduction

It is known that nuclear structure functions are not identical to the corresponding ones in the nucleon. The nuclear modification was first found by the European Muon Collaboration (EMC), so that it is called EMC effect. The phenomena have been well investigated theoretically and experimentally in the structure function F_2 [1, 2]. In recent years, the small x region has been studied extensively. The ratio $R_2 \equiv F_2^A/F_2^N$ [3] becomes smaller than unity at small x, which is referred to as shadowing in the structure function F_2. Models for explaining the F_2 shadowing include vector-meson-dominance-type models and parton-recombination-type models [4].

The former models describe the shadowing in the following way. A virtual photon transforms into vector-meson states (or $q\bar{q}$ states), which then interact with a target nucleus. The central constituents are "shadowed" due to the existence of nuclear surface constituents. The latter models explain the shadowing by interactions of partons from different nucleons in a nucleus, and the interactions are called parton recombinations. They become important especially at small x, where the longitudinal localization size of a parton exceeds the average nucleon separation in the nucleus.

Because these two different ideas produce similar shadowing results in F_2, it is difficult to distinguish among the models in comparison with experimental data. If accurate experimental F_2 data are obtained [5], it is perhaps possible to find the "correct" explanation. However, a better idea could be to look for other shadowing observables. We discuss in this paper that a promising way of testing the models could be to use the structure function F_3.

Except for the nuclear effects on F_2, modification of sea-quark and gluon distributions [6] has been discussed recently. However, there is another interesting point to be investigated. It is the structure function F_3 in nuclei. In a naive parton model without next-to-leading-order corrections, F_3 is given by valence-quark distributions. Therefore, the ratio $R_3 \equiv F_3^A/F_3^N$ in the medium x region should be well estimated from existing experimental data for R_2. So the essential point of our investigation is to study the small x region. Although there is a certain restriction on R_3 due to baryon-number conservation, the F_3 shadowing is an undeveloped research area.

The purpose of our research is to investigate whether or not studies of the F_3 shadowing help us discriminate among different models, which produce similar results on the F_2 shadowing. In section 2, nuclear shadowing in F_3 is investigated in two models: 1) a parton recombination model with Q^2 rescaling effects and 2) an aligned-jet model. Then, using the existing data of R_2 and the conservation rule, we estimate an acceptable F_3 shadowing region. Our conclusions are given in section 3.

2. Shadowing in the structure function $\mathbf{F_3(x)}$

We discuss model predictions of the nuclear-structure-function ratio R_3. In particular, two different models are employed. The first model is the parton-recombination model with Q^2 rescaling in Ref. [2]. The second model is the aligned-jet model by Frankfurt, Liuti, and Strikman [7, 8]. This model is based on the vector-meson-dominance model but it is modified due to $q\bar{q}$ continuum.

2.1 A parton-recombination model with $\mathbf{Q^2}$ rescaling

After the EMC finding of nuclear modification in 1983, there are many publications on the topic. There is no unique explanation for the EMC effect unfortunately. However, it is the fact that similar results are obtained in completely different models, for example, in a macroscopic model of nuclear binding and in a microscopic model of Q^2 rescaling. This duality is interpreted in the following way [9, 10]. As there is freedom to choose the renormalization point in an operator product expansion, the factorization scale in convolution formalism is not defined. A different factorization scale corresponds to a different interpretation of the EMC effect. In this sense, we could connect seemingly different models by a single scale change, which is called rescaling. According to Ref. [10], nuclear structure functions $F_2^A(x, Q^2)$ are given by rescaling Q^2 in the nucleon structure function $F_2^N(x, Q^2)$.

We use this Q^2 rescaling model with parton recombinations [2]. The rescaling model was originally proposed as a model for explaining the medium x region, and the recombination [11] as a model in the small x region. Using these two mechanisms, we explained the structure function F_2^A from very small x to large x [2]. This unified model can be applied to the structure function F_3. In the naive parton model, the F_3 structure function of the nucleon is given by $F_3(x) = xu_v(x) + xd_v(x)$. The formalism in Ref. [2] is used in calculating the valence-quark distributions. The initial Q^2 was chosen at 0.8 GeV^2 in calculating the rescaling and the recombinations; however, the resulting evolution shows little Q^2 dependence in the ratio R_2. Calculated results at Q^2=0.8 GeV^2 are shown in Fig. 1 for the calcium nucleus. The dashed curve shows the Q^2 rescaling results. The ratio R_3 in the medium x region is almost equal to the EMC effect in F_2. As x increases, the ratio becomes smaller and typical nuclear effects are 10% in the medium size nucleus. Because the Q^2 rescaling satisfies the baryon-number conservation, the ratio R_3 becomes larger as x decreases. There are other important effects at small x due to parton recombinations. Their contributions on $F_3(x)$ are rather contrary to those in the Q^2 rescaling model as shown in Fig. 1. The recombinations decrease the ratio at small x and increase it at medium and large x. In the model of Ref. [2], the valence-quark number is conserved, so that the ratio is above unity at small x due to the medium x suppression. The overall nuclear modification is very interesting in the sense that the ratio R_3 is much different from the one for the

structure function $F_2(x)$ at small x. In this parton model, the F_3 shadowing differs distinctively from the F_2 one:

$$\frac{F_3^A(x)}{F_3^N(x)} \neq \frac{F_2^A(x)}{F_2^N(x)} \quad \text{at small } x \quad . \tag{2.1}$$

In other words, valence-quark modification is different from the sea-quark one. It is especially interesting to find in Fig. 1 that the model predicts *antishadowing* in the structure function F_3 instead of shadowing.

2.2 An aligned-jet model

Within the parton model in subsection 2.1, the F_3 modification at small x is very different from the F_2 one. However, the situation is not so simple. There exists a model in which F_2 and F_3 shadowing predications are similar. It is an aligned-jet model, for example, the one investigated in Ref. [7, 8]. It is based on a traditional idea, the vector-meson-dominance model. The virtual photon transforms into vector-meson states, which interact with a target. The propagation length of the hadronic fluctuation is estimated by $\lambda \approx 1/|E_H - E_\gamma| \approx 0.2/x$ fm. The length exceeds the average nucleon separation in a nucleus at small x, so that shadowing phenomena occur due to multiple scatterings.

The aligned-jet model is an extension of this model. The virtual photon (or W) transforms into a $q\bar{q}$ pair, which then interacts with the target. However, the only $q\bar{q}$ pair aligned in the direction of γ (W) interacts in a similar way to the vector-meson interactions with the target. In this model, vector-meson-like $q\bar{q}$ pairs interact with sea quarks and valence quarks in the same manner. Therefore, the F_3 shadowing is very similar to the F_2 one. In fact, the shadowing results in figure 3 of Ref. [8] are similar to those of the F_2 shadowing:

$$\frac{F_3^A(x)}{F_3^N(x)} \approx \frac{F_2^A(x)}{F_2^N(x)} \quad \text{at small } x \quad . \tag{2.2}$$

It is interesting to find that the aligned-jet model predicts the shadowing, which is contrary to the antishadowing in the first parton model. In the following, we discuss whether or not both possibilities are allowed within existing data and the baryon-number conservation.

2.3 Experimental restriction and comparison

We find that the calculated F_3 results are much different in both models. In this subsection, an experimental restriction on the F_3 shadowing is discussed. If next-to-leading-order effects are neglected, the F_3 structure function is identical to the valence-quark distribution: $F_3(x) = u_v(x) + d_v(x) \equiv V(x)$. We assume $R_V \equiv V_A(x)/V_N(x) = R_3$ in our investigation. The F_2 structure function at medium and large x is dominated by the valence-quark distributions. Therefore, the ratio R_3 for the structure function F_3 at medium and large x should be equal to R_2, which has been measured experimentally. The major point of our study is then to estimate the small x region. There is a restriction on the valence-quark modification due to the baryon-number conservation $\int dx V(x) = 3$. Because the ratio R_3 is less than unity at medium x, there are two major possibilities at small x. One is that the ratio increases as x decreases (antishadowing), and the other is that the ratio is significantly enhanced at $x \approx 0.1$ and it becomes smaller than unity at very small x (shadowing).

In order to study these possibilities, we assume that the ratio R_V at $x > 0.3$ is equal to R_2 by neglecting sea-quark contributions. SLAC experimental data R_2 [12] of the calcium nucleus are shown in Fig. 2 in the x region, $x > 0.3$. These data are fitted by a smooth analytical function shown by a solid curve. We extrapolate the curve into the small x region by considering the baryon-number conservation. First, a straight line in the logarithmic x is simply drawn from x=0.3 as shown by the dashed line in Fig. 2 so that it satisfies the conservation rule. The line is roughly the upper limit of nuclear modification. Second, the curve is smoothly extrapolated into the small x region by allowing about 6% antishadowing at $x = 0.1-0.2$. Considering experimental antishadowing in F_2 at $x = 0.1 - 0.2$ [13] and a nuclear sea-quark distribution [14], we think that 6% is roughly an upper bound for the valence-quark antishadowing in this region. If accurate data are obtained in R_2 and in the sea-quark-distribution ratio $S_A(x)/S_N(x)$ at $x = 0.1 - 0.2$, we could have a better estimate of the antishadowing. Because of this antishadowing, the ratio could become smaller than unity at very small x in order to satisfy the conservation. This dotted curve at small x is considered to be a rough lower bound for the nuclear modification. The shaded area between these curves is the area of possible nuclear modification, which is allowed by present experimental data of R_2 and the baryon-number conservation. It should be emphasized that the region is a very naive estimate of the experimental restriction.

It is noteworthy that the first parton-model (model 1) prediction is roughly equal to the upper bound curve, and the aligned-jet model (model 2) prediction is to the lower bound curve. So the models are two extreme cases, which are both acceptable in our present knowledge. We have not investigated the details of other model predictions. However, it is very encouraging to investigate the (anti)shadowing phenomena of F_3 in the sense that the observable could be useful in discriminating among different models, which produce similar results in the F_2 shadowing.

There are reasonably accurate data for F_3 of a medium size nucleus, but we do not

have accurate deuteron data [15]. We hope that future neutrino experiments provide us accurate information on nuclear modification of F_3.

3. Conclusions

We investigated nuclear modification of the structure function F_3 in two different models: the parton-recombination with Q^2 rescaling and the aligned-jet model. These two models predict completely different behavior at small x: antishadowing in the first model and shadowing in the second model. Within our present experimental and theoretical knowledge, both results are allowed even though they are two extreme cases. Therefore, it is possible to rule out one possibility by measuring F_3^A/F_3^D. Furthermore, the F_3 shadowing could be useful in discriminating among various shadowing models. Our investigation is merely a starting point in studying details of the F_3 shadowing. In particular, other model predictions and experimental possibility should be explored.

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References

[1] For a summary of the EMC effect, see E. L. Berger and F. Coester, Annu. Rev. Nucl. Part. Sci. 37 (1987) 463 ; R. P. Bickerstaff and A. W. Thomas, J. Phys. G 15 (1989) 1523; R. P. Bickerstaff, M. C. Birse, and G. A. Miller, Phys. Rev. D 33 (1986) 3228.

[2] S. Kumano, Phys. Rev. C 48 (1993) 2016; Phys. Rev. C 50 (1994) 1247.

[3] The nuclear structure function per nucleon is used throughout this paper.

[4] See the papers listed in Ref. [2].

[5] A. Brüll and C. Scholz (NMC collaboration), personal communications (1994).

[6] S. Kumano, Phys. Lett. B 298 (1993) 171; Phys. Lett. B 342 (1994) 339.

[7] L. L. Frankfurt and M. I. Strikman, Phys. Rep. 160 (1988) 235; Nucl. Phys. B 316 (1989) 340.

[8] L. L. Frankfurt, M. I. Strikman, and S. Liuti, Phys. Rev. Lett. 65 (1990) 1725; research in progress.

[9] R. G. Roberts, *The Structure of the Proton* (Cambridge University Press, Cambridge, 1990).

[10] F. E. Close, R. G. Roberts, and G. G. Ross, Nucl. Phys. B 296 (1988) 582; F. E. Close, R. L. Jaffe, R. G. Roberts, and G. G. Ross, Phys. Rev. D 31 (1985) 1004.

[11] A. H. Mueller and J. Qiu, Nucl. Phys. B 268 (1986) 427; J. Qiu, Nucl. Phys. B 291 (1987) 746; F. E. Close, J. Qiu, and R. G. Roberts, Phys. Rev. D 40 (1989) 2820.

[12] J. Gomez et al. (SLAC-E139 collaboration), Phys. Rev. D 49 (1994) 4348.

[13] P. Amaudruz et al. (NMC collaboration), Z. Phys. C 51 (1991) 387.

[14] D. M. Alde et al. (Fermilab-E772 collaboration), Phys. Rev. Lett. 64 (1990) 2479.

[15] D. Allasia et al. (CERN-WA25 collaboration), Z. Phys. C 28 (1985) 321; J. Guy et al., Z. Phys. C 36 (1987) 337.

Figure Captions

Fig. 1 Nuclear modification of F_3 in the calcium nucleus is predicted in the parton recombination model with Q^2 rescaling. The dashed curve shows the results in the Q^2 rescaling model. Effects of the parton recombinations are shown by the arrows. The overall results including the rescaling and the recombinations are shown by the solid curve.

Fig. 2 The model-1 curve is the predication of the nuclear modification of F_3 in the calcium by the parton model in subsection 2.1, and the model-2 curve is the one by the aligned-jet model. The dashed and dotted curves are estimated by using existing data of F_2^{Ca}/F_2^D at $x > 0.3$ and the baryon-number conservation. The shaded area is roughly the currently acceptable region. Note that the experimental data are for F_2^{Ca}/F_2^D.

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